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LINEARIZED TRAVELING WAVE TUBE CIRCUIT WITH PRE-DISTORTION LINEARIZER

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Technical Field

The present invention relates generally to communication satellites, and more particularly, to a traveling wave tube circuit for communication satellites.

Background Art

Traveling wave tube amplifiers, or traveling wave tubes as they are sometimes referred to, commonly consist of a vacuum tube RF high power amplifier. In most applications for space systems, the high power traveling wave tube amplifier is positioned some distance away from a predistortion linearizer and electronic power conditioner due to the differing operating temperature ranges of these devices. Commonly, the linearizer and power conditioner use solid state components and therefore require a lower operating temperature than the traveling wave tube amplifier. Commonly, an RF interconnecting cable is used to couple the traveling wave tube amplifier and the RF amplifiers and predistortion network. Such a device is shown in prior art Fig. 1 having an RF input 10 coupled to an RF amplifier 12 which in turn is coupled in series with a predistortion network 14. The predistortion network 14 is coupled to a second RF amplifier 16. The second RF amplifier 16 is coupled to the traveling wave tube amplifier 18 by an RF connecting cable 20. The RF amplifier 12, predistortion network 14 and RF amplifier 16 are located in a low temperaturc zone 22. The traveling wave tube 18 is positioned in a high temperature zone 24.

One problem with such a design is that the RF connecting cable 20 must be accounted for when performing an RF alignment of the linearizer with the traveling wave tube amplifier 18. When the alignment is completed with a specific cable length, any changes to thc cable length may changc the

characteristics of the circuit and therefore the alignment process needs to be repeated.

Another drawback to the system is that the predistortion network is typically comprised of field effect transistors (FETs). These devices have limited operating range for reliable operation.

It would therefore be desirable to provide a traveling wave tube amplifier and predistortion network circuit integrated as a single unit that does not require alignment if the cable length is changed.

Summary Of The Invention

It would therefore be desirable to provide an improved traveling wave tube amplifier circuit that allows design flexibility for the spacecraft. It is a further object of the invention to provide a passive linearizer capable of operating at high temperatures to eliminate the effect of the RF connecting cable on the design of the circuit.

In one aspect of the invention, a traveling wave tube amplifier assembly has a traveling wave tube, a predistortion network coupled to the traveling wave tube and physically coupled to the traveling wave tube. An amplifier is separated from the traveling wave tube and the predistortion network by a connecting cable coupled to the amplifier and the predistortion network. In a preferred embodiment of the invention, the predistortion network and traveling wave tube are located in a high temperature zone and the RF amplifier is located in a lower temperature zone than the high temperature zone.

One advantage of the invention is that the cable length may be changed to accommodate various designs process without having to perform another alignment process.

Other objects and features of the present invention will become apparent when viewed in light of the detailed description of the preferred embodiment when taken in conjunction with the attached drawings and appended claims.

Brief Description of the Drawings

Figure 1 is a schematic view of a prior art traveling wave tube amplifier circuit.

Figure 2 is a schematic view of a traveling wave tube amplifier circuit according to the present invention.

Figure 3 is a schematic view of a predistortion network of Figure 2.

Figure 4 is a output power versus input power of the circuit of Figure 3.

Figure 5 is a plot of the circuit of Figure 3 used in Figure 2 illustrating output power versus input power.

Figure 6 is transfer characteristic for a traveling wave tube showing output power versus input power.

Figure 7 is an output versus input power plot of a linearized traveling wave tube using the circuit of Figure 3 and the transfer characteristics of Figure 6.

Figure 8A is a plot of C/3IM or NPR plot versus output backoff that illustrates the linearized traveling wave tube characteristic of the circuit of Figure 7.

Figure 8B is a plot of NPR versus output backoff of the circuit plotted in Figure 7.

Figurc 9 is a schematic view of an alternative predistortion network according to the present invention.

Figurc 10 is an output power versus input power transfer characteristic of the circuit of Figurc 9.

Figure 11 is a transfer characteristic plot showing output power versus input power using the predistortion network of Figure 9 with a traveling wave tube having the characteristics of Figure 6.

Figure 12A is a plot of C/3IM performance of the traveling wave tube circuit of Figure 11.

Figure 12 is a plot of NPR versus output backoff showing the NPR performance of the linearized traveling wave tube circuit of Figure 11.

Detailed Description of the Invention

In the following description, the same reference numerals will be used to identify the same components in thc various views. Although specific configurations are illustrated, those skilled in the art will recognize various alternative embodimcnts and configurations may be possible according to thc teachings of thc present invention.

Referring now to Figure 2, although other uses are possible, the present invention is illustratcd with respect to a spacecraft generally represented by rcfcrcncc numeral 30. Spacccraft 30 has a traveling wave tube amplificr circuit 32 according to thc present invention. The circuit 32 has an RF input 34

that is coupled to a first RF amplifier 36. The first RF amplifier 36 has an output coupled to a second RF amplifier 38. Although two RF amplifiers are illustrated, those skilled in the art will recognize that a combination amplifier having the features of RF amplifier 36 and RF amplifier 38 may be formed.

An RF connecting cable 40 is coupled to the output of RF amplifier 38. RF connecting cable 40 couples RF amplifier 38 to a predistortion network 42. The predistortion network 42 is coupled physically to traveling wave tube amplifier 44. Also, the predistortion network 42 is coupled elcctrically in series with traveling wave tube 44 and the output of RF amplifier 38. The traveling wave tube 44 has an RF output 46.

RF amplifiers 36 and 38 are located in a low temperature zone 48 and predistortion network 42 and traveling wave tube 44 are located in a high temperature zone. For example, the low temperature zone may be about 65°C. High temperature zone 50 may, for example, be about 85°C. Thus, the predistortion network 42 is separated from the components for RF amplification, namely the first RF amplifier 36 and the second RF amplifier 38.

Traveling wave tube amplifier 44 is preferably a vacuum tube high power amplifier. The traveling wave tube is a high power amplifier and operates efficiently at a high operating temperature such as the high temperature zone 50.

Referring now to Figure 3, the predistortion network 42 is illustrated having an RF input 51, a limiter 52 coupled in series with the RF input. Limiter 52 is coupled in series with a first attenuator 54. The first attenuator 54 is coupled in series with a phase shifter 56 and the phase shifter 56 is coupled in series with a second attenuator 58. The operation of the limiter 52, attenuator 54, phase shifter 56, and attenuator 58 are well known in the art.

Also, the predistortion network 42 has a transmission line 60 coupled in parallel with a series connection of limiter 52, attenuator 54, and phase shifter 56. Both ends of transmission line 60 are coupled to a ground termination 62. Predistortion network 42 is preferably formed of robust components such as PIN diodes that operate at higher temperatures than the field effect transistors (FETs). Advantageously, the predistortion network 42 may be located with the traveling wave tube 44 and the high temperature zone 50 that allows the independence of the circuit and the alignment process on the RF connecting cable 40.

Referring now to Figure 4, the transfer characteristic of the first limiter 52 is illustrated. As those skilled in the art will recognize, the transfer characteristics of the limiter 52 has power levels suitable for inputs to a traveling wave to amplifier. This eliminates the need for amplification stage 16 between the predistortion network and the traveling wave tube. As illustrated, the relative phase is plotted with respect to output power. The bold line is relative phase; and, the thin line is output power. The elimination of amplifier stage 16 allows for operation at high temperature

Referring now to Figure 5, when a linearizer having the transfer characteristics shown in Figure 4 is used in the circuit of Figure 3, the output of predistortion network 42 shown in Figure 5 may be obtained.

Referring now to Figure 6, a transfer characteristic of a suitable traveling wave tube is shown. Both output power and relative phase are illustrated.

Referring now to Figure 7, when the traveling wave tube transfer characteristic shown is combined with the linearizer having a transfer

characteristic shown in Figure 5, the traveling wave tube amplifier 32 is illustrated in Figure 7.

Referring now to Figures 8a and 8b, a traveling wave tube amplifier circuit performance is shown. In Figure 8a, the C3IM performance is illustrated for the amplifier circuit having the transfer characteristics shown in Figure 7. Also, Figure 8b illustrates the NPR transfer characteristics.

Referring now to Figure 9, the same reference numerals are used to illustrate the same components of Figure 3. An alternative embodiment of a predistortion network 42' is illustrated. In a similar manner to that shown in Figure 3, an RF input 41 is coupled with the series combination of a first limiter 52 and a first attenuator 54, a phase shifter 56 and a second attenuator 58. In addition, the transmission line 60 has a third attenuator 66 coupled in series with a second limiter 68. An attenuation of 5.5dB for third attenuator 66 was used in the predistortion network. Adjustment of the attenuator will allow the network 42' to be used with a family of different traveling wave tubes with input powers that vary ± 2.5 dB.

Referring now to Figure 10, the transfer characteristic of the predistortion network 42' is illustrated.

Referring now to Figure 11, the transfer characteristic of the traveling wave tube amplifier circuit 32 having a predistortion network 42' and a traveling wave tube characteristic 56 is illustrated.

Referring now to Figures 12a and 12b, the performance of the traveling wave tube amplifier circuit having a predistortion network 42' is illustrated. In Figure 12a, the C3IM performance is illustrated. In Figure 12b, the NPR transfer characteristic is illustrated.

In operation, because the predistortion network 42 is capable of being located within high temperature zone 50, the alignment process of the circuit is considerably reduced. Thus, once the circuit is formed and the alignment is performed, no further alignments are required if the length of the RF connecting cable is changed.

While particular embodiments of the invention have been shown and described, numerous variations alternate embodiments will occur to those skilled in the art. Accordingly, it is intended that the invention be limited only in terms of the appended claims.